Power-to-X for the future fuels supply

Techno economic evaluation and system analysis

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18. October 2017
Ferankfurt/Main

Agenda

1. Motivation Power-to-X
- Need for GHG emission reduction
- GHG emissions in Germany
- Options to reduce GHG emissions

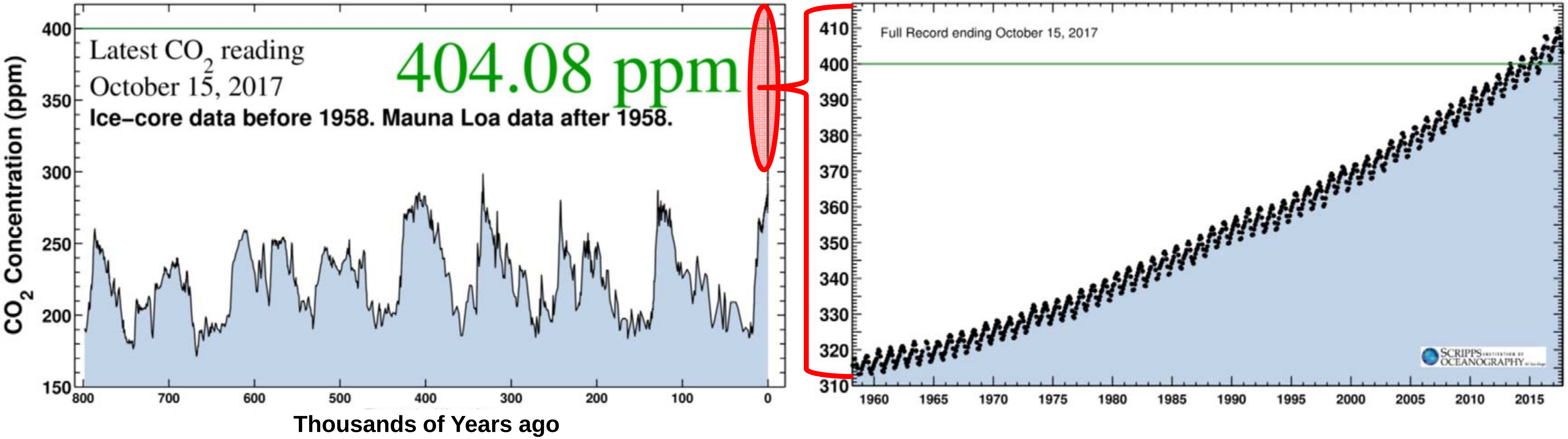
2. Power-to-X concepts
- PtX-Options
- Evaluation criteria of PtX-Concepts

3. Process evaluation of Power-to-X
- Introduction to DLR methodology
- Example: PtL – Jet fuel by Fischer-Tropsch

4. Summary and Outlook

Climate Change – Driver for Power-to-X?

No slow-down of carbon dioxid concentration rise to observe!



Source: https://www.co2.earth/daily-co2

Global agreement to mitigate climate change

Global long term targets

- COP21 targets:

❖ Decarbonization of Society

❖ Global average temperature increase below 1.5 °C

European mid term goals

- EU-targets until 2030[1,2]

❖ **40 %** reduction of GHG (base year 1990)

❖ **27 %** increase of renewable energies in primary energy consumption

❖ **10 %** renewable energy in transport and **6.8 %** advanced renewable fuels in fuel supply

[1] European Council, "2030 Climate and Energy Policy Framework," Brussels 2014

[2] European Commission, "Proposal for a directive on the promotion of the use of energy from renewable sources (recast)," Brussels 2016

CO_2 Emissions from Germany


Bundesministerium für Wirtschaft und Energie
WIRTSCHAFT. WACHSTUM. WOHLSTAND.

Zahlen und Fakten Energiedaten

Nationale und Internationale Entwicklung

Die Energiedaten gliedern sich in die Abschnitte
0. Inhalt, Erläuterungen, Einheiten
1. Rahmendaten
2. Energiegewinnung und Energieverbrauch
3. Energie und Umwelt
4. Energieträger
5. Energiepreise und Energiekosten
6. Internationaler Energiemarkt
7. Reserven und Ressourcen
8. Energieforschung

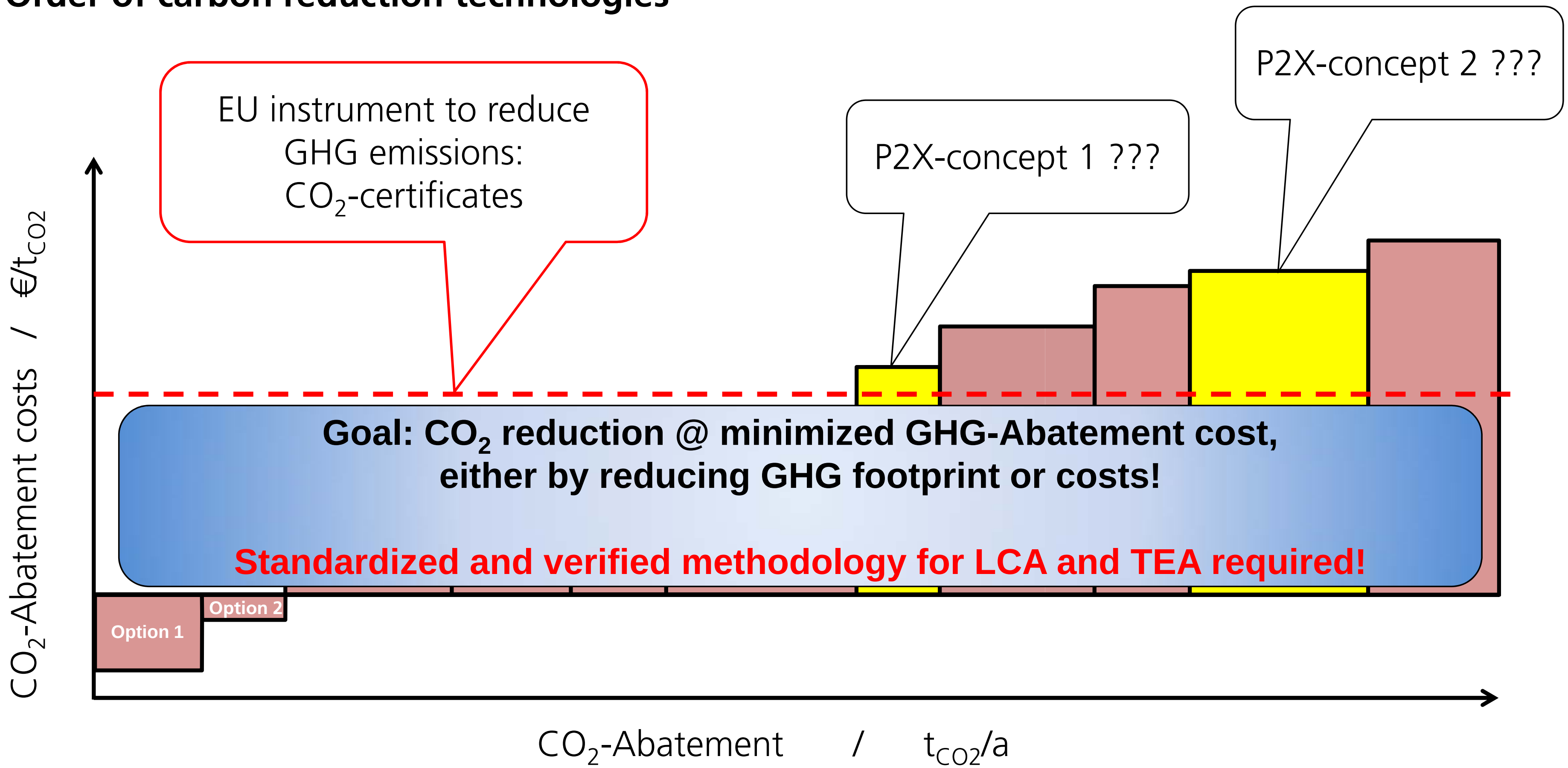
https://www.bmwi.de/Redaktion/DE/Binaer/Energiedaten/energiedaten-gesamt-xls
letzte Aktualisierung: 05.05.2017

How to reduce Carbon Footprint?

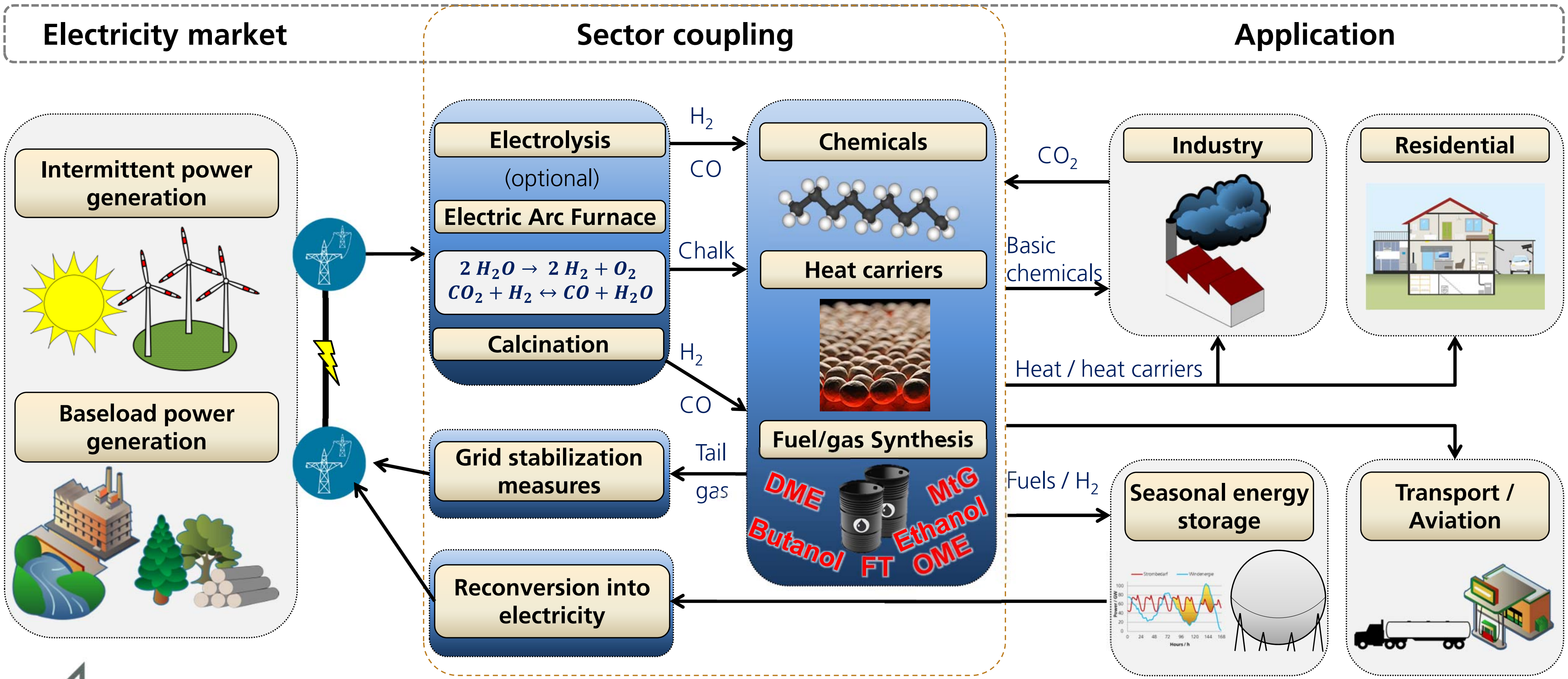
CO_2 / Mt_{2015}	Energy / PJ_{2015}	
148.5		Wind, PV, ~~biomass~~, ~~nuclear~~ PtX
171.6		Wind, PV, ~~biomass~~, ~~nuclear~~
245.6		e-Mobility, ~~biofuels~~, PtX
150.7		PtX

Comparison of PtX concepts

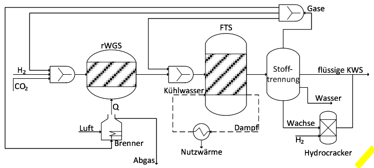
Merit-Order of carbon reduction technologies



2. Power-to-X concepts – part of a new integrated energy system

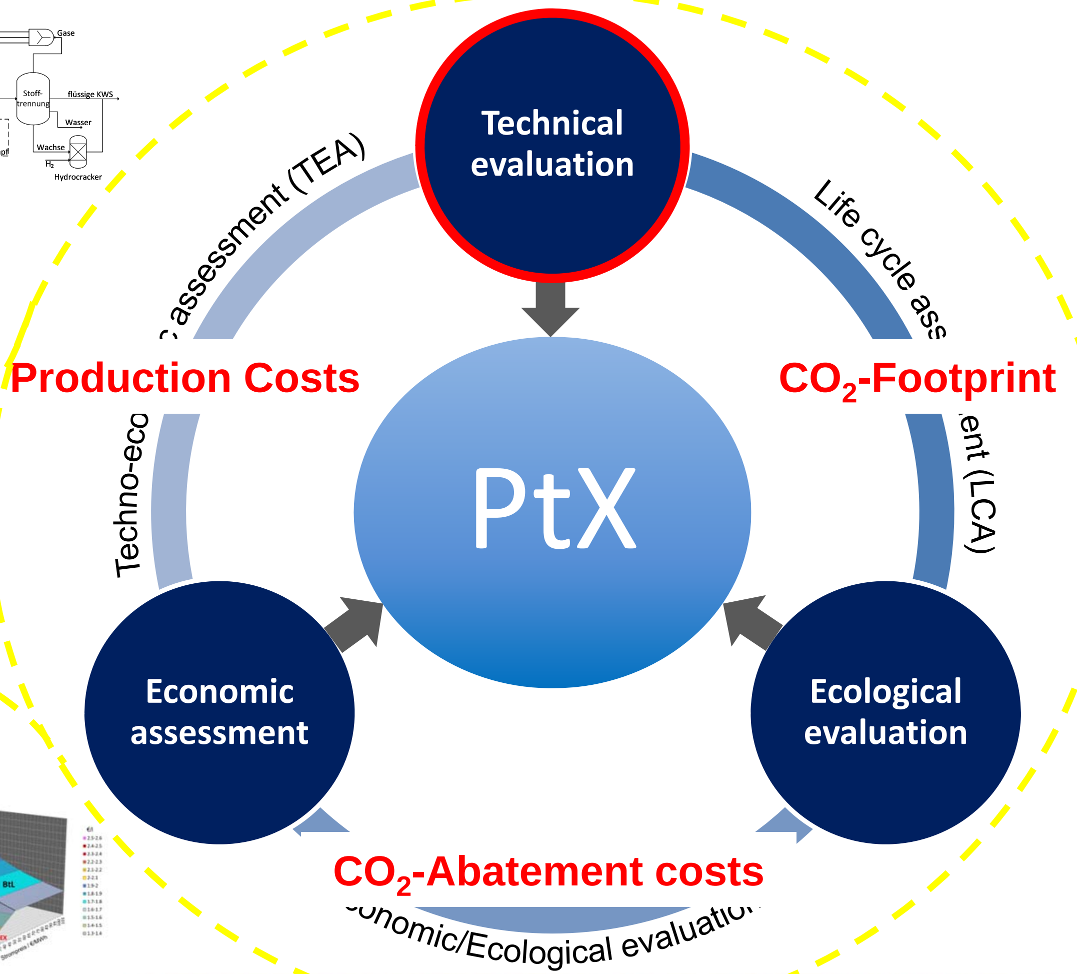


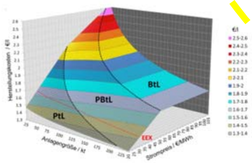
3. Process evaluation of Power-to-X – Methodology @ DLR



DLR-evaluation and optimization tool

TEPET
Powered by DLR
Standardizing economic process evaluations





Example: PtL – Jet fuel by Fischer-Tropsch

Renewable power

H_2O electrolysis

Electrolyzer options:

- Alkaline electrolyzer
- Polymer electrolyte membrane (PEM)
- High-temperature electrolysis (SOEC)

$3H_2$ → Synthesis gas production

CO_2 → Synthesis gas production

Synthesis gas production → CO + 2 H_2 → Fischer-Tropsch synthesis → Jet fuel upgrading

CO_2 separation → CO_2

Carbon Sources:

- Power Plants
- Industry (Cement, Iron&Steel, Chemical, Petroleum industry)
- Biomass
- Air

ASTM 7566
max. 50 % drop-in

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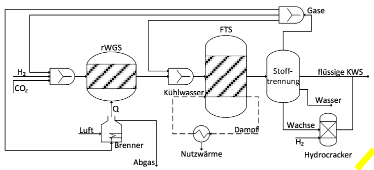

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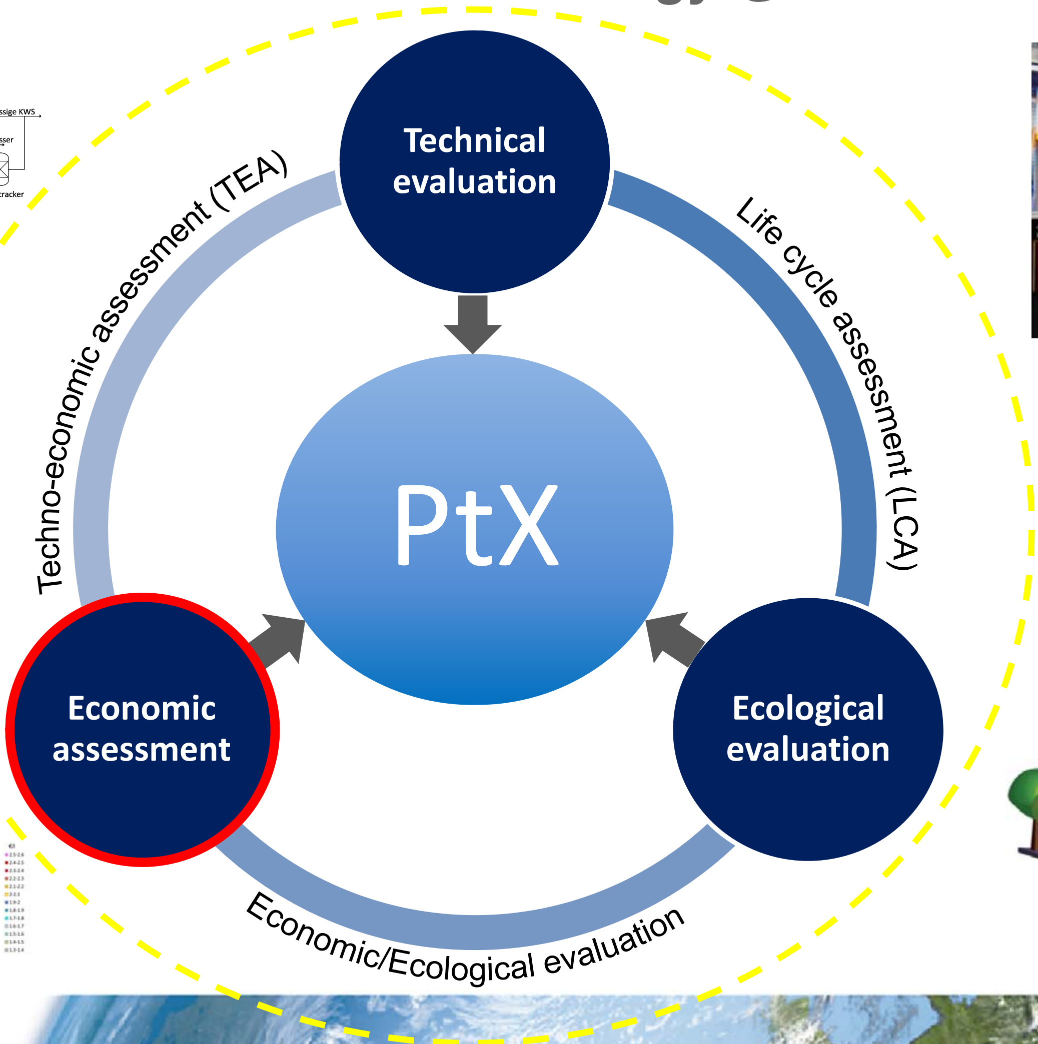
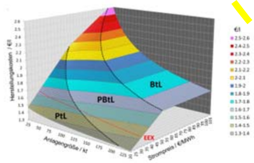
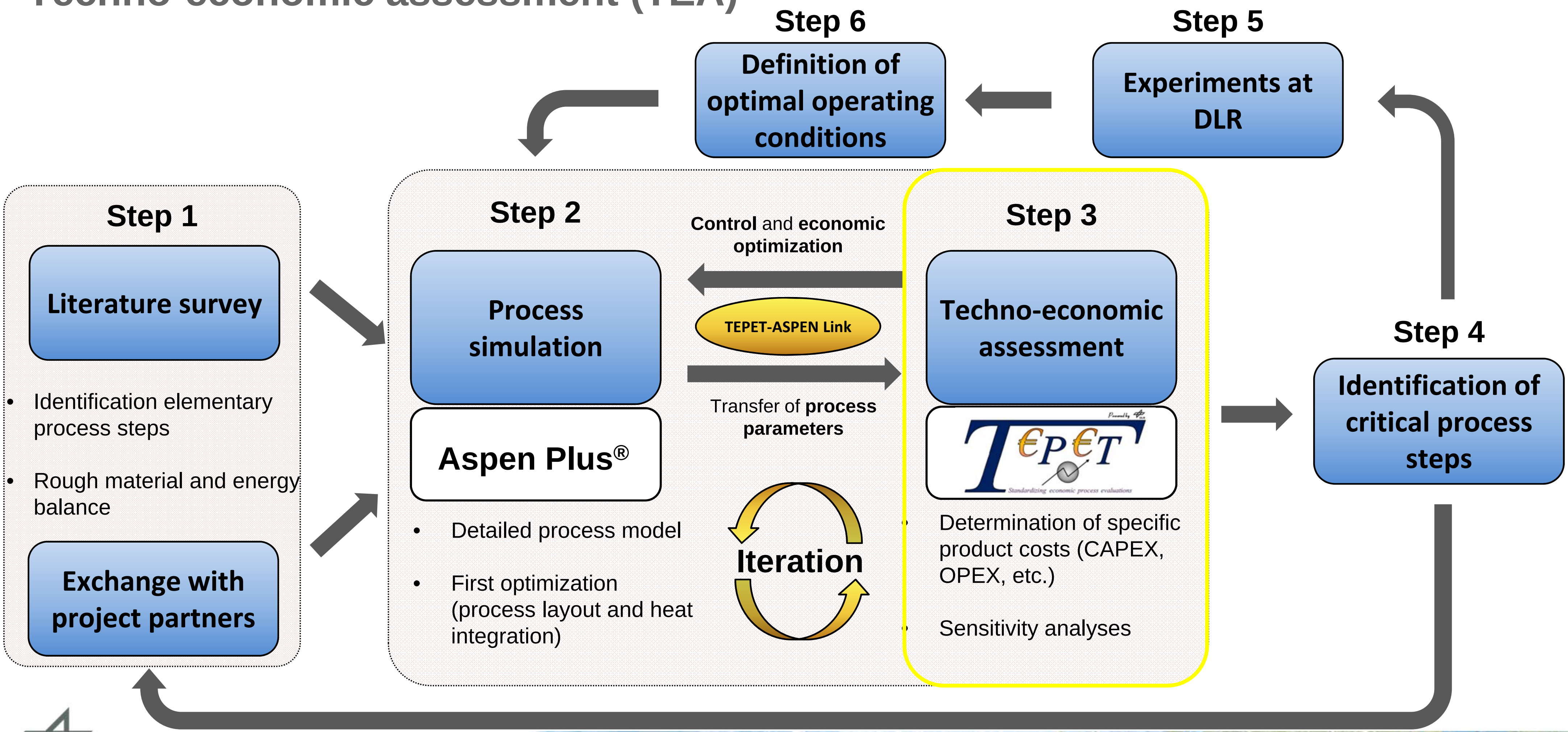


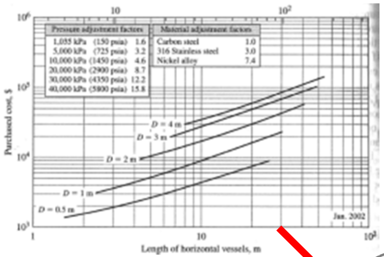


Techno-economic assessment (TEA)



TEA Methodology

- adapted from **best-practice chem. eng. methodology**
- Meets AACE class 3-4, Accuracy: **+/- 30 %**
- **Year specific** using annual CEPCI Index
- Automated interface for **seamless integration**
- Easy sensitivity studies for **every** parameter
- Learning curves, economy of scale, …



Direct cost factors		
Installation factor:	0.25	x Equip. cost
Instrumentation and control:	0.22	x Equip. cost
Piping system:	0.05	x Equip. cost
Electrical systems:	0.1	x Equip. cost
Buildings:	0	x Equip. cost
Yard improvments:	0	x Equip. cost
Service facilities:	0	x Equip. cost
Indirect cost factors		
Engineering and supervision:	0	x Equip. cost
Construction expenses:	0	x Equip. cost
Legal expenses:	0	x Equip. cost
Contractor's fee:	0	x D+I
Contingency:	0.1	x D+I

Process simulation results

Plant and unit sizes

material and energy balance

Aspen Plus®

TEPET-ASPEN Link

TEPET Standardizing economic process evaluations

Capital costs

- Equipment costs
- Piping & installation
- Factory buildings
- Engineering services …

Operational costs

- Raw materials
- Operating materials
- Maintenance
- Wages …

Production costs
€/l , €/kg , €/MJ

eex

DESTATIS wissen.nutzen.

Example: PtL – Boundary conditions dictate economic results

2016 investment costs:			
PEM-Electrolyzer (stack):	**720**	€/kW [1]	
PEM-Electrolyzer (system):	**1,350**	€/kW	(TEPET)
Fischer-Tropsch:	**95,650**	€/(m³)[2]	(scale factor 1)
2016 raw material & by-product market prices:			
Electricity:	**83.7**	€/MWh[3]	
CO_2:	**12.1**	€/t [4]	
Oxygen (export):	**23.7**	€/t [5]	
Steam (export):	**14.7**	€/t [6]	

Other economic assumptions:

Base year:	2016	*Plant lifetime:*	30 years
Operating hours:	8,260 h/a	*Interest rate*	5 %

[1] G. Saur, Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study, Technical Report NREL, 2008
[2] P. Kerdoncuff, Modellierung und Bewertung von Prozessketten zur Herstellung von Biokraftstoffen der zweiten Generation, Dissertation, KIT, Karlsruhe, 2008
[3] Eurostat, Preise Elektrizität für Industrieabnehmer in Deutschland, 2016
[4] S. D. Phillips, „Gasoline from wood via integrated gasification, synthesis, and methanol-to-gasoline technologies," NREL, 2011
[5] NREL,"Appendix B: Carbon Dioxide Capture Technology Sheets - Oxygen Production," US Department of Energy, 2013
[6] Own calculations based on natural gas price from Eurostat database

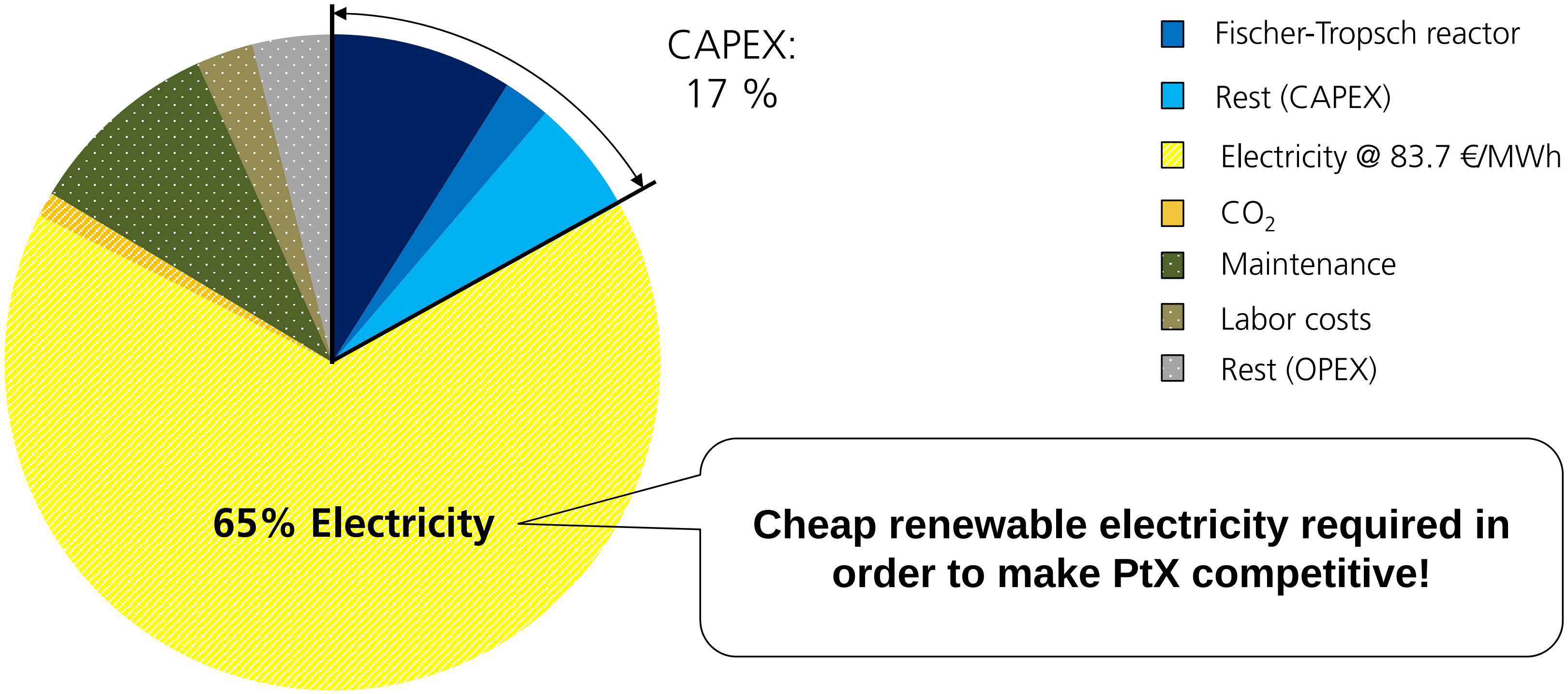
Example: PtL – Jet fuel production via Power-to-Liquid

Plant capacity: 107 kt/a (1 % of German jet fuel consumption) – Base year: 2016

Power-to-Liquid (PtL)

Investment: 755 mio. €

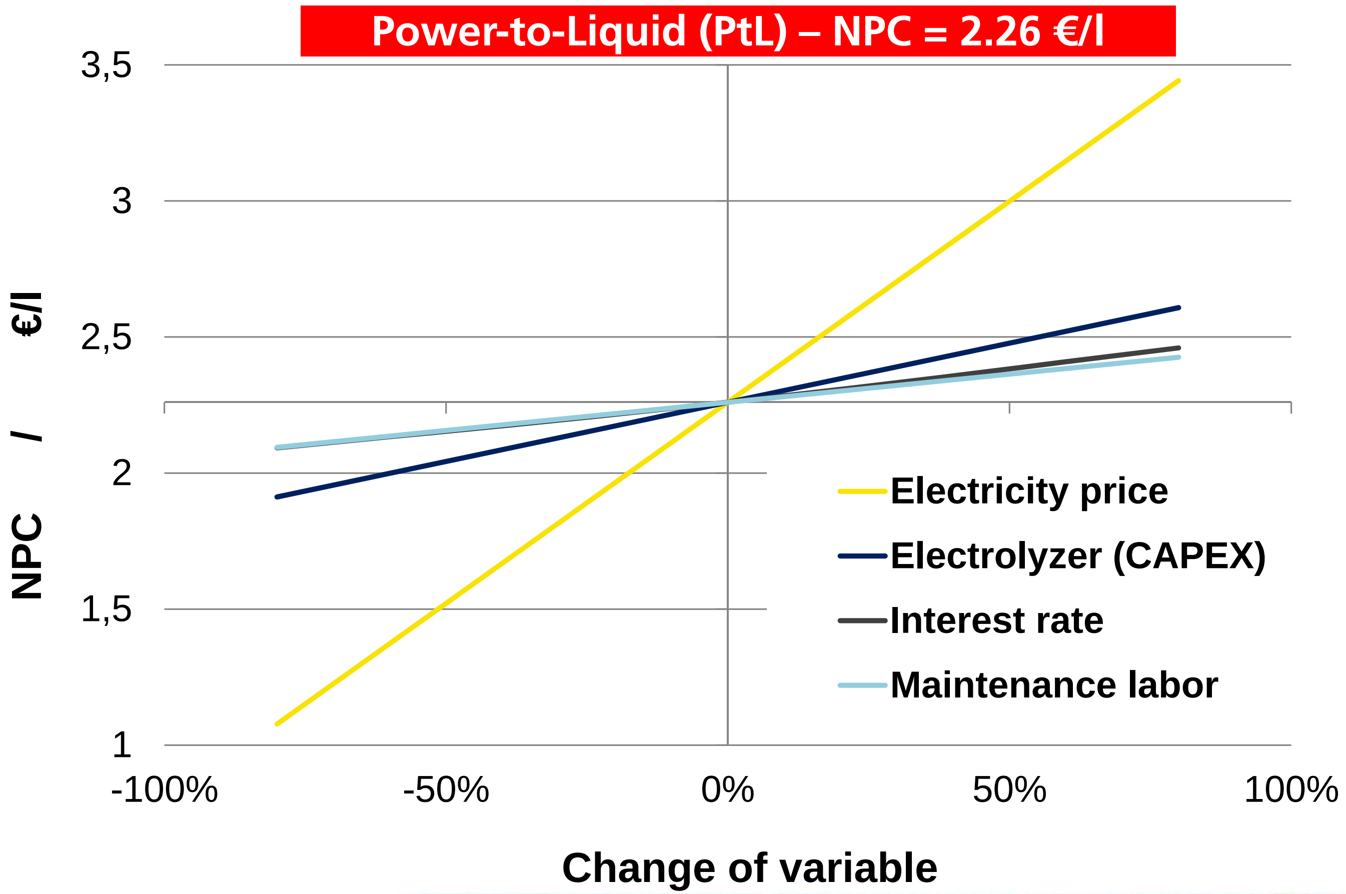
Production costs: **2.26 €/l**



Cheap renewable electricity required in order to make PtX competitive!

Example: PtL – Jet fuel production sensitivity analysis

Plant capacity: 107 kt/a (1 % of German jet fuel consumption) – Base year: 2016



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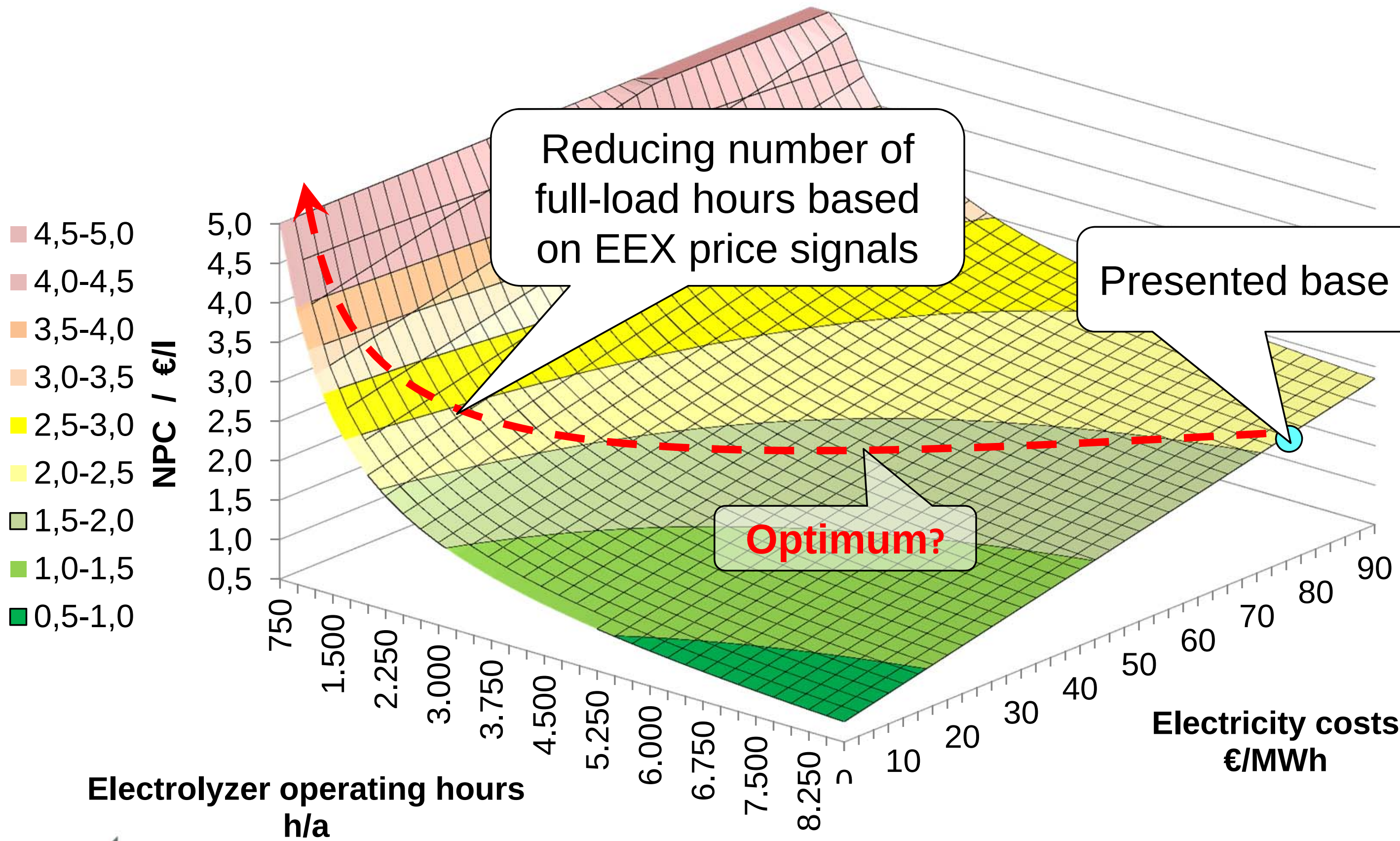
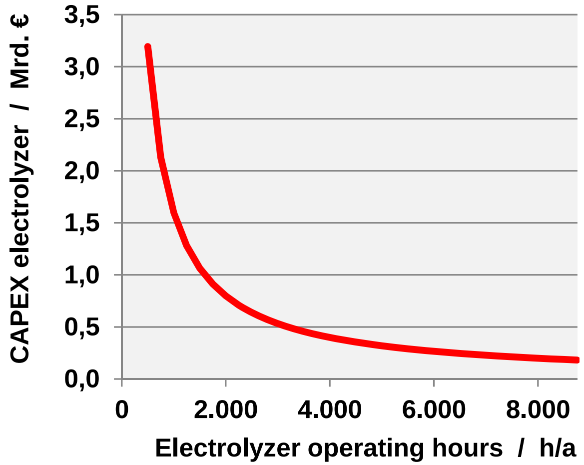
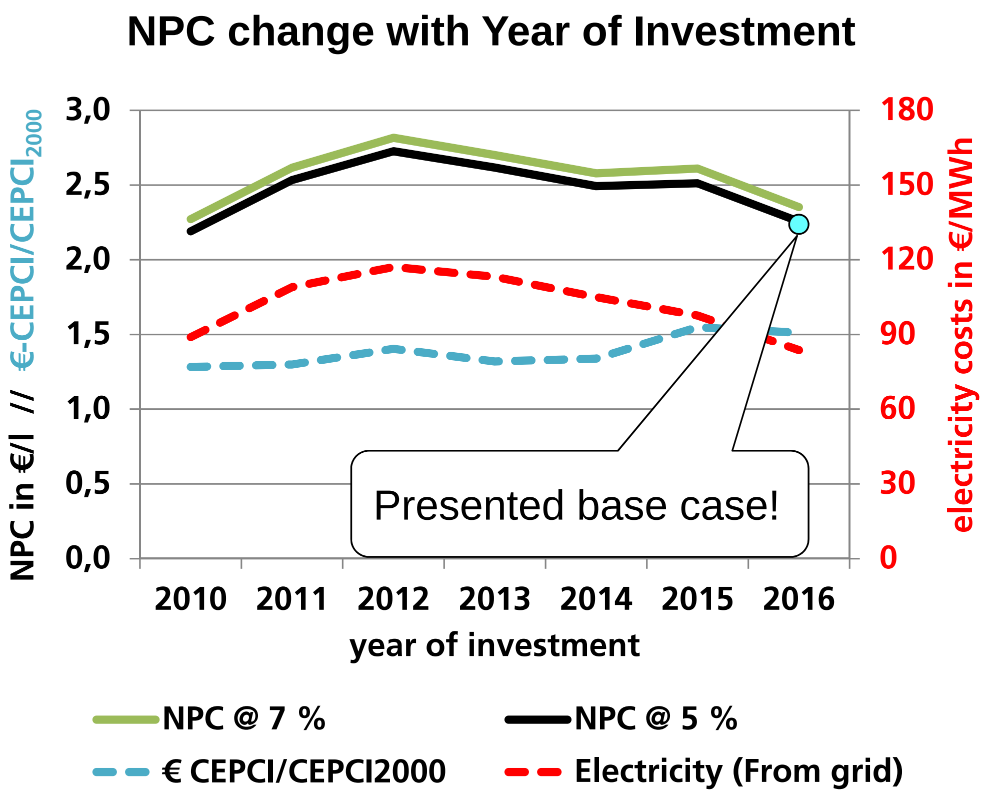
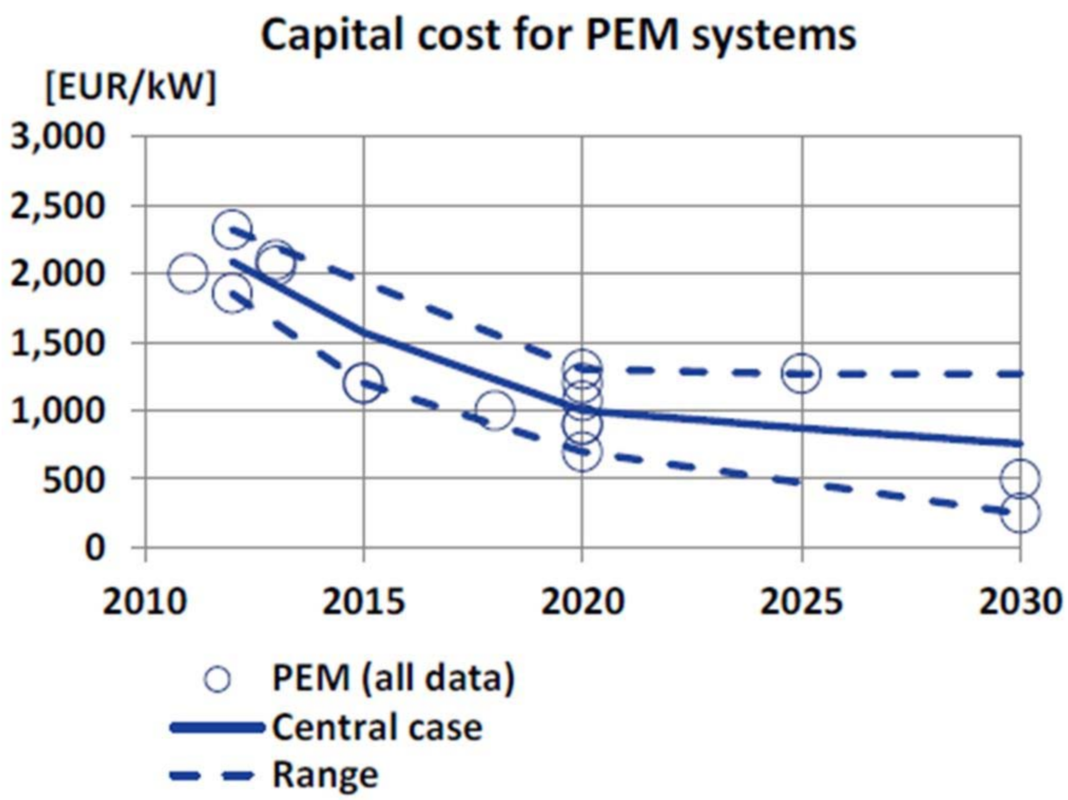




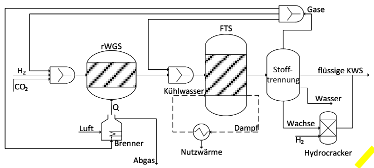
Prices of 2016 are not going to last – only year specific costs are comparable

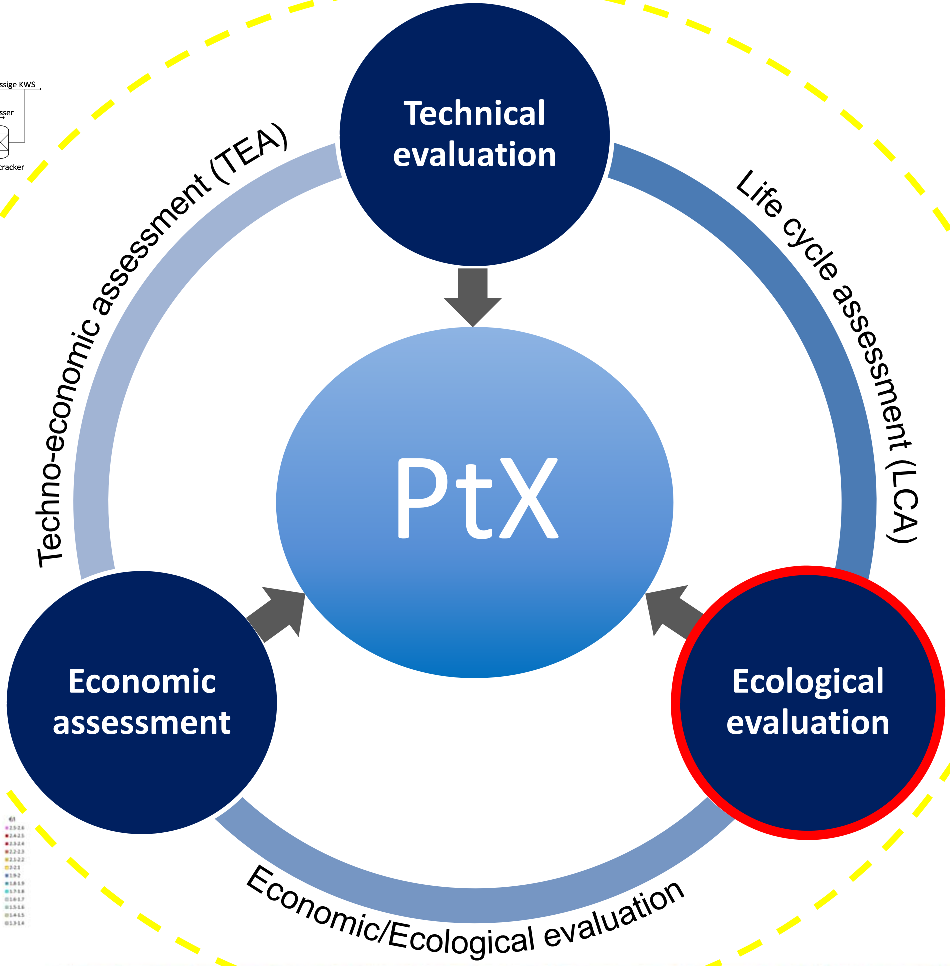




source: FCHJU, "Development of water electrolysis in the EU", Feb 2014

3. Process evaluation of Power-to-X – Methodology @ DLR





DLR-evaluation and optimization tool

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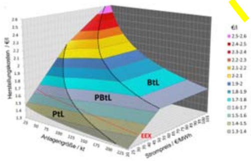
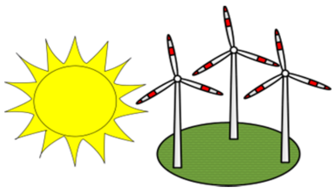


DLR

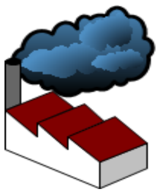
Example: PtL – GHG-Footprint Calculation

Carbon footprint of used raw materials and energy sources defines carbon footprint of product!

Power footprint



Carbon dioxide footprint



Black box

System integration

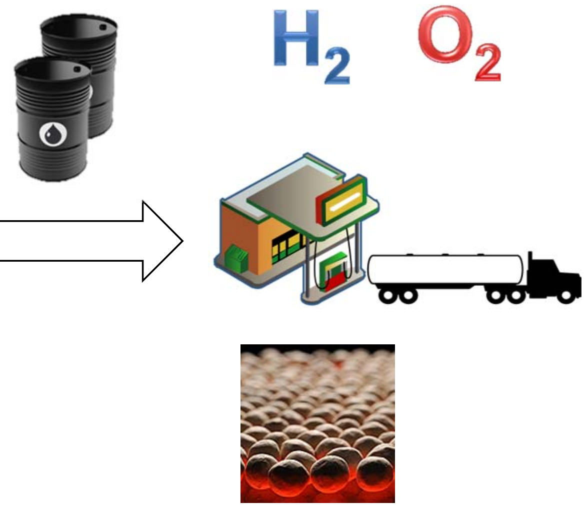
Plant efficiency

PtX - Concept

Plant emissions

Accounting for by-products

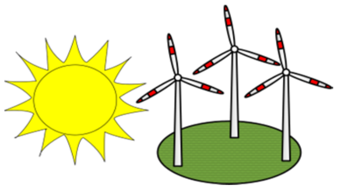
Footprint of products: Fuel/heat/H_2 etc.



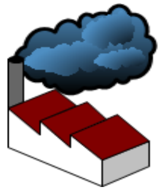
$$CO_2 - Abatement\ costs \left[\frac{€}{t_{CO_2}}\right] = \frac{Difference\ in\ fuel/heat/H_2\ costs}{CO_2 - emission\ reduction}$$

Example: PtL – GHG-Footprint boundary Conditions

Power



Carbon dioxide



Oxygen

O_2

Functional unit	[kg$_{CO2eq}$/MWh][a]	[kg$_{CO2eq}$/t][b]	[kg$_{CO2eq}$/t][c]
Low boundary	10	5	100
Average	272.5	77.5	250
High boundary	535	150	400

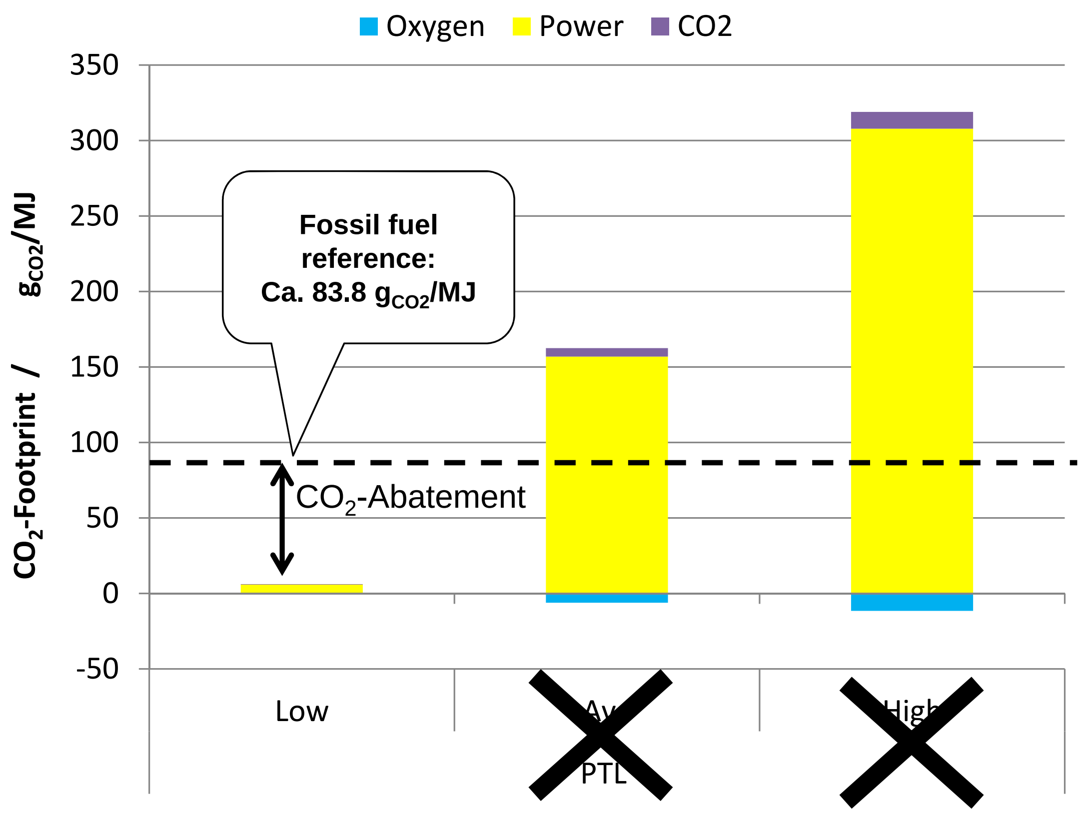
[a] Low boundary value for pure wind electricity taken from [1]. High value corresponds to the actual CO_2-footprint of the German electricity sector [2].

[b] Based on own calculations. The carbon footprint represents emissions arising from sequestration of CO_2 from flue gas. Flue gas from cement industry and coal fired power plants were investigated. The probably fossil nature of the flue gas was not taken into account. Low/high value: energy demand of CO2-sequestration from cement plant/ coal fired power plant is covered with wind energy/German electricity mix.

[c] Taken from ProBas databank [1]. Low/high value due to different electricity sources.

[1] Umweltbundesamt, “Prozessorientierte Basisdaten für Umweltmanagementsysteme,” http://www.probas.umweltbundesamt.de/php/index.php.
[2] Umweltbundesamt, “Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix in den Jahren 1990 – 2016,“ Dessau-Roßlau,2017.

Example: PtL – From CO_2-Footprint to CO_2-Abatement costs



PtL-concepts viable when using renewable power only!

CO_2-Abatement costs:

Case1 – Current State:

Price of fossil kerosene: ca. 0.5 €/l
Grid Power price: 83.7 €/MWh
Plant capacity: 107 kt/a

Case2 – Pressure on Fossil Fuels:

Price of fossil kerosene: ca. 1 €/l
Renewable Power price: 30 €/MWh
Plant capacity: 1,000 kt/a

CO_2-Abatement costs	€ / t_{CO_2}
Case	PtL-Low
1	650
2	92.3

Current Price of CO_2-European Emission Allowances:
ca. 5 - 8 €/t_{CO2}

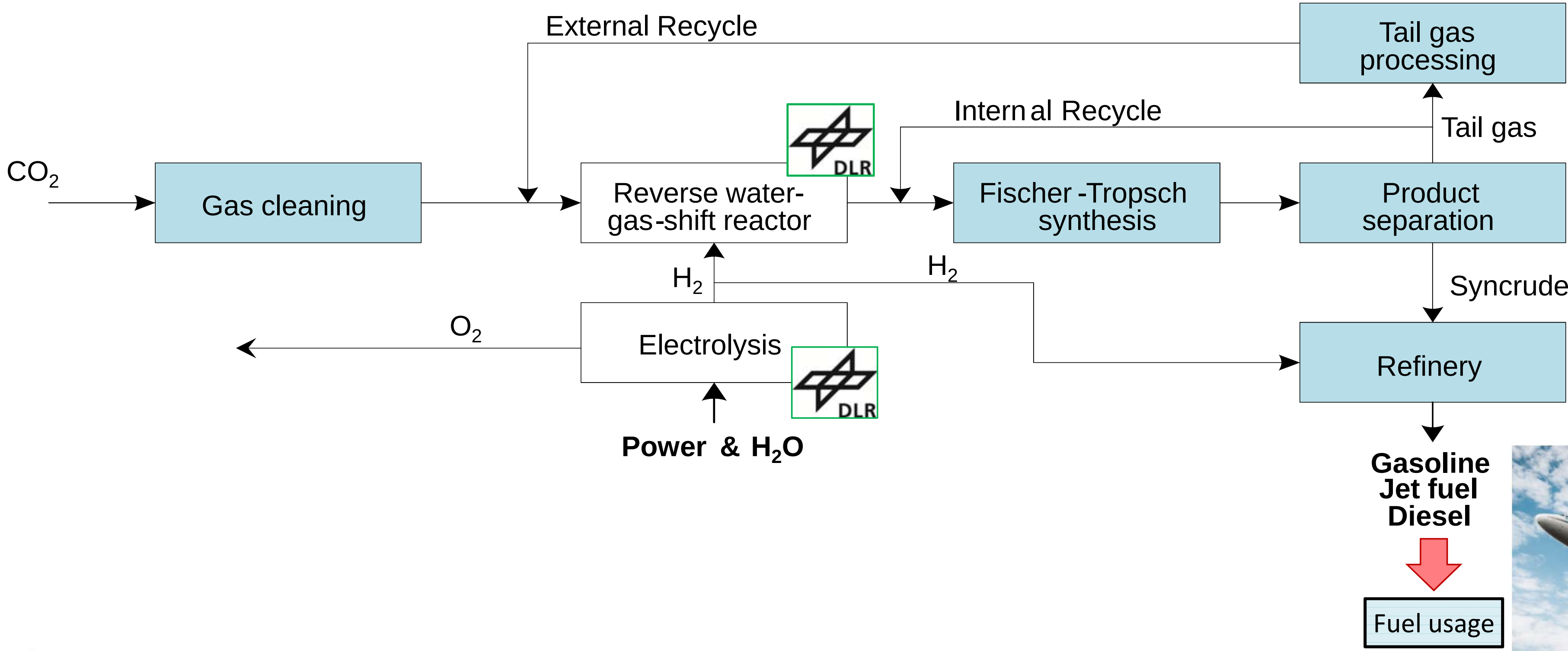
DLR

4. Summary & Outlook

- **PtX is required to meet the aviation contribution (and more) for the German climate protection targets**
- Volatile renewable power sources have large (theoretical) potential in Germany
- Coping with fluctuating power input is key challenge for the PtX concept
- Viability of PtX concepts highly depends on GHG footprint and GHG abatement costs
- Evaluating PtX concepts requires standardization and common agreement on the methodology
- Transparent and open published DLR methodology for cost estimation and GHG-footprint calculation offers a starting point for future unified technology assessment
- **PtX R&D, Demo, Market Introduction into sustainable aviation need to start NOW**

Outlook – PTL demonstration for sustainable Aviation

Techno-economic assessment



THANK YOU FOR YOUR ATTENTION!

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